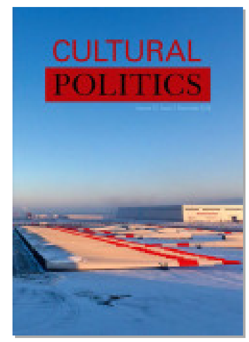
Thermocultures of Geological Media

Nicole Starosielski



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Abstract **This article documents how thermal manipulation is critical to the transformation of the earth's raw materials into media and to maintaining those materials as media. Through an examination of thermal practices, including mineral extraction, the use of air-conditioning in media manufacturing and preservation, and thermal infrared imaging, thermal control is shown to be essential to the conversion of geological matter into circulations of media on a mass scale. In each of these cases, cultural assumptions and imperatives—the drive toward purity, the development of standardization, and the demand for homogeneity across elements and media objects—organize temperature management. The thermocultures of media inflect its composition, movements, and temporalities and embed it within existing regimes of capitalism, gender, race, and sexuality. The study of thermocultures offers an alternative to traditional infrastructural and geological analyses, one oriented less toward the excavation of elements from deep time and the depths of the earth and more toward the conditions in which geologic matter's potentials are actualized as media. It also opens up a new set of genealogies for investigation, including the historical role of thermal management in the differentiation of gendered bodies.**

Keywords **media, geology, infrastructure, heat, temperature**

The impact of an explosion—the result of contact between ammonium nitrate, fuel oil, and the spark of a detonator—shakes the earth's surface, extending a mining company's access to minerals. A fiber-optic cable snakes through an underground tunnel. Slight variations in temperature produce oscillations in the cable's glass fibers, scattering the light in minute ways that are instantly recorded in an operations center

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above. Ore is transported to a furnace and heated to several thousand degrees Fahrenheit until it melts into a fiery orange liquid. After it is drawn into a thin wire, pulses of electricity channel through the line. Cables enter a data center, where air conditioners pump cool air through the building and servers are separated into "hot" and "cold" aisles. Signals flood a computer. A system overheats and crashes.

In these moments, media's materiality is composed and recomposed in relation to shifting temperatures. Minerals, themselves formed through the heating and cooling of the earth, are extracted using thermal technologies. Manufacturers' ability to precisely control temperature enables the conversion of metals into standardized components. When cooling apparatuses fail, the heat generated by digital media inhibits its operation. In consumer use, media technologies only operate within specific temperature ranges, failing in conditions that are too hot or too cold. After media is extracted, assembled, and circulated, thermal manipulation makes preservation possible—chilled in data centers and archives. Whether via furnaces or air conditioners, ductwork or cables, the manipulation of heat is critical to the transformation of the earth's raw materials into media and to maintaining those materials *as* media.

Studies of culture have long drawn upon the language of temperature, from Karl Marx's and Friedrich Engels's well-cited description that "all that is solid melts into air" (see Marx 1978: 476), to Claude Lévi-Strauss's (1966) "hot" and "cold" societies, to the "hot rocks" of the Cold War (see Armstrong 2008). Temperature has also had a formative influence on the analysis of media and communication. Information theory, in particular Claude Shannon's mid-century work, drew heavily from thermodynamics, and Marshall McLuhan (1964) famously divided media into "hot" and "cool" forms. A number of scholars have tracked the way that heating and cooling has shaped the built environment, including its thermal delights (Heschong 1979), the architectural aesthetics of heat (Ong 2012), and technological air-conditions (Sloterdijk 2009). The study of temperature's wide-ranging impacts on cultural production, especially beyond the field of architecture, has been less widespread than its symbolic uptake, perhaps a legacy of the racialized environmental determinism of writers such as Montesquieu and Ellsworth Huntington. Little has been written on the multitude of thermal practices that entangle forms of mediation with heat, even as these are both challenged by and contribute to global climate change.[1]

This article tracks one set of thermal practices: the techniques through which geological matter is transformed into circulations of media on a mass scale. Perhaps most obviously, this includes the use of heat to refine "raw" minerals into media. In the first section, I argue that thermal extraction, a process governed by the imperative of purification, has enabled digital networks to become near-instantaneous technologies of global communication. Temperature is regulated to ensure not only the purity of specific materials but also consistency across media objects. In the second section, I describe how thermal technologies underpin the standardization of culture, decreasing the distinctiveness of otherwise heterogeneous media objects and facilitating their circulation as global commodities. This is visible in media production, as well as in the use of heating and cooling to stabilize media over time, a key defense in the fight against decay. Even with such attempts to homogenize media and culture in a world of variable temperature, materials continue to register minute thermal variations. In the third section, I turn to recent exploitations of geological thermosensitivities that turn the earth into a source of heat signals. Techniques of thermal sensing are now proving instrumental to the extractive industries and the study of geology more broadly.

This critical analysis of media's thermal conditions in sites of mineral extraction and technological production expands our understanding of the geophysical environments, extractive practices, and nonorganic compositions that constitute media forms—what Jussi Parikka (2015) has called a "geology of media." The geology of media, and the broader geological turn in cultural studies, has aimed not only to introduce a new set of objects and processes to the study of culture but to reconfigure how we think about life, bodies, and media—as composed of and in geological matter. The "geological conditions of the human" and our bodily composition, Kathryn Yusoff (2013) argues, extend from our originary mineralization to our fossilized ends. Likewise, the geological conditions and composition of media extend from its elemental components through its disintegration in piles of e-waste around the world. Rather than unearthing particular geological elements, such as coltan or copper, this article's focus on thermal environments directs attention to the processes through which geologic matter becomes or ceases to be media. Despite the hardness of the ground, it is far from a stable bedrock of media or culture. Geological materiality is in flux, its seemingly solid entities "teeming with material potentials that can be teased out in different constellations, temperatures, and conditions" (Parikka 2015: 23). Thermal techniques are operations that produce "cuts" in this flux (Barad 2007), tease out different material potentials, and shape "solid" media out of geological substances.

Like all technoscientific practices, thermal techniques and the divisions they enact are permeated by cultural logics. The drive toward purity that structures the thermal production of digital hardware is neither necessary nor neutral. It is designed specifically to reduce error and compartmentalize digital content. Thermal systems underwritten by other cultural logics, perhaps ones that made compromises in speed and accuracy, would generate less environmental impact and significantly alter the form of existing media texts and technologies. In place of the drive toward homogeneity in the thermal practices of media reproduction, we might imagine a tolerance for subtle variations across media objects that would reshape media's movement and meaning in the world. Understanding media's thermocultures reveals not only the limits of geology's mediating capacities but the matrix of cultural practices that structure these limitations.

Thermocultures embed media's production within existing regimes of capitalism, gender, race, and sexuality and direct the geology of media sideways—from the site of excavation to the smelter, from the miner to the metallurgist, and from media's constituent parts to the architectures in which they are housed. As a result, the study of thermocultures offers an alternative to the temporal and spatial orientation of many infrastructural and geological analyses, a redirection from the depths of the earth and its histories to the conditions in which material potentials are actualized as mediating forms. It also brings with it an alternate set of genealogies, which I turn to briefly in the final section of this article. In particular, thermal techniques have long been a site for the differentiation of gendered bodies. In addition to digging and drilling, techniques of baking, alchemy, and other forms of thermal management play a role in the history of geological media and prompt consideration of differentially subjugated bodies alongside fossils, dirt, and elements.

The Purity of Elements

Let us start where so much of geology does: with the minerals embedded in the earth's crust. Copper and silicon, as Jennifer Gabrys (2011), Richard Maxwell and Toby Miller (2012), and Jussi Parikka (2015) have observed, are indispensible for circuits of global communication. Network histories tend to mark a shift from telegraph and telephone networks to the high-tech fiber-optic world, and from copper to silicon as the dominant element, but each of these has been critical in historical and contemporary media systems. Quartz crystal (silicon dioxide) was an important component in radio technology, for example, and today's optical cables and microchips require silicon. Copper was not only the conductive core for telegraph cables but is used throughout contemporary communications circuits, architectures, and power transmission systems. These elements are present in almost all contemporary digital media.

Cultural explorations of geology, whether of copper, quartz, or other materials, have often focused on the mine, the location where minerals are unearthed. Images of immense open-pit mines capture the public's attention, the gaping holes a visible imprint of human activity on the earth's surface. Narratives about the mines, as Rosalind Williams (2008: 4) argues, offer a vision of an artificial and technological world, "a prophetic view of our environmental future." Whether viewed from space by means of Google Earth or imagined as a descent into an underworld, the mine has been a primary site for the articulation of geological materiality. The cultural techniques of geological excavation are digging and drilling. Technologies of mining penetrate the land, whether dynamite, pickaxes, or massive earthmovers. In media and cultural studies, the geologic imaginary has often been closely tied to an archaeological one: movement is structured along a vertical axis, with orienting strata and retrievable elements (Elden 2013).

Although the recovery of minerals is perhaps the most well-documented aspect of geological activity, what is brought to the surface in the moment of excavation is undifferentiated heterogeneous matter. At the Morenci mine in Arizona, the largest copper mine in North America, copper is bonded to sulfur, iron, oxygen, aluminum, hydrogen, and silicon. It mingles with rocks, dirt, a range of other "valuable" minerals, electric rope shovels, monitoring systems, and Mexican laborers who have long been crucial to the mine's operations. For each ton of ore removed, only ten pounds of pure copper will be produced. On the other side of the United States, in the Spruce Pine mining district of North Carolina, quartz remains in "close assemblage" with other minerals (Purdy 1988: 1). One geological study reports that its "broken and bent" crystals are included within a "matrix" of other minerals, which "wrap around" each other in a postmagmatic deformation (Swanson and Veal 2010: 30). When the minerals are moved away from the mine by massive trucks, the resulting dust moves through the air, reattaching to roads and the lungs of local residents. In the process of excavation, copper and silicon do not exist as singular materials; the output of mining is a composite, an agglomeration no more capable of transmitting signal traffic than when it was underground.

It is impossible to locate elements as discrete phenomena at the mine. The idea that copper and silica exist as separate entities is a cultural belief already informed by their potential extractive uses. Such geological materialities remain entangled; there is no clear boundary between rock and mineral, organic and inorganic. The "cut" in such an assemblage is made through an extensive process of thermal manipulation. When copper sulfide ore is removed from a mine, it is subjected to a series of physical processes—including crushing, grinding, and mixing the ore with water and chemicals—that are intended to separate valuable minerals from the "waste rock." The result is a compound that contains around 25 percent copper. The element of Cu is only severed from this compound by means of a set of thermal techniques, including several stages of heating in furnaces that melt the concentrate, catalyze chemical reactions, and break the bonds between Cu and other "impurities." Cumulatively, these processes produce a substance that is 99 percent copper, but even this is insufficient for contemporary electronics production. In a final stage, electrolytic refining, large slabs of almost pure copper are immersed in a solution that is shot through with a current of over 200 amps, dissolving the copper atoms from the slabs and generating a material that is 99.99 percent pure.

Electronics-grade quartz production requires a similar set of techniques. After crushing and grinding equipment is used to process mined quartz lumps, a variety of sorting technologies "liberate impurities" from the crystals (Haus, Prinz, and Priess 2012: 46). The ore is also exposed to magnets and immersed in water in order to differentiate compounds and molecules on the basis of their physical sensitivities. As in the processing of copper ore, the initial physical procedures are followed by a series of temperature-dependent chemical reactions. In chemical leaching, quartz crystal is subjected to hydrofluoric acid at an elevated temperature. In hot chlorination, minerals are heated to over 1,500 degrees Fahrenheit in a chlorine or hydrogen chloride gas atmosphere. And in the stage of thermal treatment, calcination technology removes bubbles from within the silica glass. These techniques, as is true in copper refining, compose an extraordinarily pure material out of the initially heterogeneous mineral composition. The components of most contemporary electronic devices, however, are not produced from natural quartz mined from the earth but rather cultured silica glass or synthetic silicon substrates that are grown via the Czochralski process. As is true for copper or quartz extraction, the precise regulation of temperature is required to create a pure substance that will meet the standards of the communications industries.

I track through the process of mineral extraction in order to make two points. First, thermal techniques are operations that produce a division, a cut, in initially heterogeneous matter. The observation that the elements of culture are pyrotechnically generated is not a new one. Over eighty years ago, Lewis Mumford ([1934] 1955: 69) remarked: "Ores and metal are recalcitrant materials: they evade discovery and resist treatment. Only by being softened do the metals respond: where there is metal there must be fire." Yet the documentation of these processes often represents them as the simple reaction of base materials and introduced chemicals.[2] The idea of inherent elemental reactivities is suggested in the chemical formulas themselves. For example, one reaction in the roasting of copper is reported as: $2CuFeS_2(s) + 3O_2(g) \rightarrow 2FeO(s) + 2CuS(s) + 2SO_2(g)$ (European Copper Institute 2016). These representations obscure the thermal environments that make the production of elements possible, as well as the technologies of temperature manipulation, whether smelters or crucibles, that are deliberately crafted to structure copper and silicon as usable elements for media transmission.

Following from this, the modalities of thermal extraction are not equivalent to the heating and cooling of the earth that formed these elements; they are designed for particular cultural uses and enmeshed in existing sociotechnical paradigms. In the case of copper and quartz extraction, strategies of thermal manipulation are governed by a cultural imperative to achieve "purity." As Mary Douglas argues in her seminal study *Purity and Danger* ([1966] 1984), the cultural production of purity is tied to the generation of particular orderings of the world: "Ideas about separating, purifying, demarcating and punishing transgressions have as their main function to impose system on an inherently untidy experience" (4). Pollution is the by-product of such a systematic order, since "ordering involves rejecting inappropriate elements" (36). While Douglas's study focuses on a radically different source material—religion and rituals in primitive cultures—beliefs about purity and pollution circulate within the electronics and mining industries and shape the design of thermal technologies. They are deliberately crafted to remove "impurities" that "contaminate" copper. And the rocks and minerals that are removed, whether poisons such as arsenic or valuable materials such as gold, are referred to and often treated as waste products.

The cultural investment in pure materials by engineers and system builders produces a particular ordering of elements that, in turn, structures the order of digital media, especially its microtemporalities and its binary code. Copper is chosen as a transmissions material in electrical circuits and in microelectronics for its extraordinarily high level of conductivity (second only to silver). And the purity of copper enables wires to transmit at high speeds with relatively low levels of noise. The more impurities a given copper wire has, the lower the level of conductivity. When the first undersea telegraph cables were laid in the 1850s, the lower-purity copper that was available contributed to the signal's attenuation as it crossed the seas. The high-purity copper of microelectronics today offers extraordinary levels of conductivity (reducing noise), ensuring that impure elements will not react with others and generate instability. Without the emphasis on purification and its enactment via thermal technologies, digital media would appear neither instantaneous nor seamless.

A close look at the technology of the transistor reveals another effect of elemental purity and impurity: these distinctions uphold the binary system that forms the foundation of digital systems. Pure silicon is a key constituent of transistors, but at room temperature, it is nonconductive; this means that there are no free electrons to carry signals across it. The element's function as a semiconductor and its ability to switch between on and off states depend on the introduction of specific impurities, a process known as doping. The many transistors in a single computer are themselves composed of multiple layers of silicon, selectively doped with phosphorous and boron atoms in specific conditions, which can be then manipulated to carry the signal across a microchip. In T. R. Reid's (1984: 88) discussion of the process, he explicitly draws upon the imaginary of cooking:

> Semiconductor manufacturing works like a barbeque pit where hickory smoke seeps into the meat and imparts a distinctive flavor. In the diffusion process, a bar of silicon is cooked in a furnace at high heat, and then a gas containing the appropriate doping impurities . . . is pumped into the furnace. . . . In the same way that a barbeque chef knows just how long to cook the ribs to get the right taste of hickory, solid-state physicists gradually determined the proper time and temperature needed to put the precise amounts of impurities at precise points on the silicon block.

While the initial purity of silicon itself is important, it is only through the precise control of impurities via thermal manipulation that the transistor can function as a switch. Without such techniques, signals would experience near constant interference at a subatomic level. The manipulation of purity through temperature is thus tied to a cultural investment both in accelerating the speed of microprocessors and in upholding the functioning of binary code—a digital system in which noise becomes a pollutant to the symbolic order.

The division of materials from one another—operations enacted under the regime of purity and in the interest of increasing media's speed and reliability—are directly tied to environmental pollution. The excess rock discarded from the mine itself is only one part of its waste. The chemicals used and emitted from smelters, deemed impurities in the refining process, are a toxic by-product. Following Douglas, the definition of purity—the designation of one set of phenomena as clean (in this case, the copper or silicon communications circuit)—is integrally tied to the production of pollution. The higher the purity required in a particular element or compound, the more chemicals and thermal control are needed and the more waste is generated. Less pure materials could certainly be used for mediation, but this would come with a sacrifice of both speed and regularity. It would entail designing for heterogeneous substrates, allowing for more errors, and limiting the reach and distance of transmission. The imperative of purity and its correlate pollution are made invisible, however, in attributions of essentialized identities to copper or silicon that assume these elements, incorporated into media, are the same ones excavated from mines.

Looking closely at the process of mineral extraction reveals that the copper and silicon that transmit electrons and photons do not exist in the earth but emerge as a result of sequential separations, where they are cut from other elements by means of pyrotechnical processing and reconstituted as the raw materials of transmissions media. Moreover, the selective use of heating and cooling to produce pure elements is not merely a chain of natural chemical transformations but a set of thermocultural processes intended to differentiate pure elements from polluting ones, and signal from noise, and to produce a digital order defined by speed and precision. Purity, as a cultural value, not only structures the arrangement of inorganic materials but conditions possibilities for how bodily matter can circulate through the world, whether its movements are facilitated by high-speed digital networks or inhibited by toxic substances.

Even Temperature

It is impossible to sever elements from their surroundings, despite attempts to control their internal composition and limit their interactions. Even the most pure forms of copper are never entirely pure. And raw materials incorporated into media technologies can never be completely controlled: the elements and compounds remain a lively force. The package material of integrated circuits might contain uranium and thorium impurities of only one part per billion, but the radioactive decay of these elements can nonetheless cause "soft errors" in semiconductor technologies (Kumar, Agarwal, and Jung 2013; Baumann 2005). Alpha particles migrate across elements, from the solder of the packaging to the silicon wafer. The impurities, as well as the chemicals used to produce them, filter through the environment and through the bodies of workers at mines and manufacturing plants.

Pure elements are entangled with their surrounding materialities not only by the introduction of rogue atoms or particles; they also remain in dynamic relationship with their thermal environment. Temperature plays a key role in how materials and bodies act—it shapes their agential capacities and behaviors. Even without receptors that make sense of heat and cold, all materialities exhibit some level of thermosensitivity, since they are sensitive and reactive to other materials in particular thermal states. This makes temperature a factor not only in the selection of media's raw materials (for example, silicon replaced germanium as a material for transistors in part due to its resistance to thermal variation) but also in the production of apparently identical media. As a way to mitigate media's inherent susceptibility to environmental conditions, extensive thermal practices have been developed to ensure homogeneity across media objects. If superheated furnaces are prime instruments of elemental purity, air conditioners are technologies of media's uniformity.

The first air conditioner, built in 1902 by Willis Carrier, was not intended to cool humans but, rather, to standardize media. In the late nineteenth and early twentieth century, printers and lithographers were grappling with the problem of fluctuating temperatures. As one printer noted: "There is probably no other craft that is so dependent on the preservation of an even temperature as presswork" (*Inland Printer* 1891). He reported difficulties that ranged from heat's "chemical action" on ink to the "generation of electricity in paper" during cold weather. Paper was a fickle material, expanding and contracting depending on climatic conditions. One critical obstacle encountered, especially in the development of color printing, was improper registration: as individual sheets were passed multiple times through a printer, if temperature and humidity changed, the inks would be overlaid imperfectly. The image would vary from the intended production, and each image might be slightly different from the others. As another writer of that period observed, the susceptibility of paper to climate was "one of the greatest difficulties the color printer [was] up against" (Turck 1914: 221).

The problem of temperature was not only of the external climate but of the excess heat generated by the presses themselves. Some pressrooms were full of extraordinarily hot air, and in these conditions, the pressfeeder was tasked with inserting page after page into the machine in the exact same position. The editor of the *Inland Printer* recounted: "No occupation in the printing trade is quite so monotonous as that of the pressfeeder, yet on none is greater accuracy entailed"

(*Inland Printer* 1914). It required "sustained skill and steadiness of nerve," particularly given the "enervating conditions." The temperature problem extended beyond the composition of the printed materials to the workers' bodily performance: heat affected their ability to accurately feed paper into the machine.

The problem of uneven temperature was one of both heat and cold, materializing in both the paper and the bodies of pressfeeders, as well as in the machinery itself. Even in the early twentieth century, it was still a common practice in many pressrooms to turn off the heat at the end of a winter day, leaving the iron and steel machines to cool overnight. The editor of the *Morning Citizen* reported that every morning, the machines would be cold: "It requires considerable time to warm up . . . if one put his hand upon a press or cutter he experiences a cold shock," and it was not until midday that everything worked "just right" (*Inland Printer* 1902). The expansion and contraction of metals caused problems over time, especially in composition rollers, which were much "more susceptible to temperature" (394). Although the thermosensitivity of organic substances such as paper and skin were more often observed, metals were likewise affected by their thermal environments.

In the absence of technologies for temperature control, achieving consistency across texts and images required a great deal of time and money. Allan Turck (1914: 221) recounts that "the United States Government has a standing offer of a large reward for the man who invents a printing-paper that will not distort under adverse conditions," given the amount of money lost each year on postage stamps that would expand or contract before they were cut. Some printers would wait until the climate was suitable to run their presses, but slowing down the printing process was at odds with the quick timetable demanded by the circulation of news. Presses in different climatic zones could thus operate at different speeds with differing degrees of accuracy. As one British lithographer observed: "German lithographers are greatly helped by the differences in their climate. With our varying temperature and our rather humid atmosphere, it is almost hopeless to register with precision sheets of fifty inches by forty inches. Yet Germany does this easily" (Colebrook 1915). Temperature shaped the temporalities, costs, and potential formats of the printing industry: the form and speed of media was limited by thermal variations across days, seasons, and climates.

Attempts were made to address this problem by manufacturing paper with a lower sensitivity to temperature and humidity, but ultimately the solution adopted was environmental control. According to its well-rehearsed origin story, the "father" of air-conditioning, Willis Carrier, was invited to the Brooklyn printing company Sackett & Wilhelms in 1902. The company was dealing with the typical problems of color printing: as ink was applied one layer at a time, it would misalign when the paper stock expanded and contracted, causing delays in the production schedule, producing a massive amount of waste, and resulting in poor quality (Willis Carrier 2016). Carrier designed an air-conditioning system to regulate both temperature and humidity in the plant, enabling improved replication of color images in *Judge* magazine, one of Sackett & Wilhelms's most important clients.

In the years that followed, air-conditioning systems were used to ensure precise replication and efficiency of production in many other forms of media. The Celluloid Company, one of Carrier's early clients, adopted an air-conditioning system to enhance the consistency of manufactured film. At the company's plant in Newark, New Jersey, humid weather caused white specks to form on the film, which translated to white spots on the screen when it was projected (Ingels 1952: 34). By 1921 *Scientific American* reported, "Mechanical weather is used in nearly every branch of the laboratory work of the motion picture industry from the drying of the celluloid film base to the drying of the finished film" (Mount 1921: 198). In media-industrial applications, temperature control was used both to reduce the effects of heat and to control the amount of humidity in the air, preventing damp air from altering the image and dry air from making the film brittle. As was true for the work of purification, the use of air-conditioning materialized with a cultural imperative: to reduce the amount of error and noise in media representations. Yet while the techniques of refining metals were intended to increase the rate of transmission, the adoption of air-conditioning in manufacturing environments was intended to standardize the media object.

Even as technologies of temperature regulation were enlisted in standardization, the thermosensitivities of media persisted. When magazines, film, or microchips are left to bear the thermal fluctuations of natural environments, they lose many of their mediating capacities. As a study by the Canadian Conservation Institute claims, there can be no discussion of avoiding temperature altogether in media preservation, only a consideration of preventing "incorrect temperature" (Michalski 2015). The report provides a table that correlates thermal conditions to the approximate lifetime of a media object. Black-and-white photographic negatives on glass, produced in the nineteenth century, will remain usable for approximately seventy-five years in a hot room of 30 degrees Celsius but will live fifteen hundred years at 10 degrees Celsius. Newsprint and celluloid film will last only six months if left out in the sun but in a "normal" room temperature will last a human lifetime. Magnetic media will last fifteen years in a warm room of 25 degrees Celsius but even in cold storage at 0 degrees Celsius will become unplayable after six hundred years. Incorrect temperature, the study observes, is an agent of deterioration.

Libraries and archives depend heavily on cooling technologies to maintain and preserve media; it is here that the temperature's agential effects on cultural production are widely considered, albeit as an inevitable deteriorating force that disrupts the original form and function of media. Although this certainly occurs with too-high temperatures that speed up chemical reactions and deform the media object or too-low temperatures that fracture media's materials, most thermal practices of preservation are devoted to maintaining an even temperature, preventing the natural fluctuations over the course of a day or a year. Different materials—whether paper made up of wood pulp, film with a nitrocellulose base, or microchips with silicon wafers—have their own thermosensitivities and expand, contract, and react with adjacent materials depending on the climate; quick or repeated movement between thermal states destabilizes the media object. Fernando Domínguez Rubio (2014: 620) argues that architectures such as museums, through such expansive technologies of climate control, become "'objectification machine[s]' that [endeavor] to transform and stabilize artworks as meaningful 'objects' that can be exhibited, classified, and circulated."

Just as standard temperatures were developed for media manufacturing, they were also developed for the preservation of media. The American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO), alongside many organizations dedicated to media preservation, have set baselines for media's thermal environments. But as is true for the logic of purification that dictates mineral refining, the thermal manipulation of media's production and storage environments is guided by cultural investments: in the expansion of the lifetime of the media object, in its crystallization in a particular form that mirrors the moment of production, and in its ability to represent a given historical moment. The object, standardized across environments and stabilized over time via thermal techniques, is endowed with an essentialized identity: the newspaper, the celluloid film, and the magnetic tape all appear self-evident, but their status as media remains heavily dependent on modes of environmental control. Just as the rate of transmission is underwritten by the imperative of purity and the thermal capacities of autoclaves and smelters, the maintenance of objectness is underwritten by the cooling capacities of air-conditioning.

Both of the thermal techniques discussed above—the standardization of the factory's internal climate and the stabilization of the media object over time in archives—appear to reduce the amount of waste generated in media production and circulation. Many early adopters of air-conditioning in media manufacture lauded the efficiency of the temperature-controlled factory since fewer materials had to be discarded as a result of "defects." And the stabilization of media in archives and other thermally controlled environments kept them from degrading and thus becoming waste. In each of these cases, however, the shift to energy-intensive cooling mechanisms substitutes the waste of media objects for the waste produced by fossil fuels. The release of heat and carbon dioxide was an externality unaccounted for in these discourses. At the same time, as more and more elements are integrated in complex ways into media technologies, each with its own reactivities and temperature dependencies, these technologies, as a whole, have become much more thermosensitive, requiring ever more controlled environments.

In the case of digital media, the temperature dependency of media technologies has reached a point where air-conditioning systems initially developed for the standardization of materials are required for its very operation. As electrons are funneled through the varied components of digital media, they give off heat that, if not managed, inhibits the machine's functionality. The extraordinary speed of conduction through pure materials generates an "incorrect temperature." In turn, as Finn Brunton (2015: 159) argues, "the work of computation is the work of managing heat." Heat is managed to some degree by the incorporation of devices that redirect excess heat, such as fans and heat sinks, but in large data centers, enormous cooling mechanisms are required to maintain the optimal temperature and ensure the stability of the computer's operation. The very objectness of any computational device is thus, from the moment it begins to compute, critically tied to strategies to maintain an even temperature.

Productive Variation

Thermocultural practices have reduced the variation of cultural production, ensuring consistency across raw materials and across media objects over time. Yet such modes of environmental control are always incomplete. Even with expansive thermal infrastructures that attempt to purify, standardize, and stabilize geological (or organic) matter, temperature remains a force that affects all thermosensitive bodies. In recent years, these variations have also been harnessed to productive ends for the expansion of media and capital, especially in the extractive industries. Fiber-optic cables have been used not only to transmit messages between humans and computers but as a sensing mechanism to detect activity in the environments they extend through, often via thermal changes. These cable systems, and the minute temperature variations that they register, are used extensively in mines, oil wells, and natural gas installations.

In fiber-optic cables, it is precisely the failure to produce a totally pure silica glass that makes the capability of earth sensing possible. David Hill, chief technology officer of OptaSense, a company that trademarked "The Earth's Nervous System," observes that even though glass fiber is "the purest material man has ever made," there is still enough "inhomogeneity" to produce backscatter as light moves down the glass fibers (quoted in *Digital Energy Journal* 2015). This backscatter is generated as light comes into contact with the fiber's molecules and lattice structure, which then redirect light at slightly different wavelengths. Some of these waves have "a unique temperature dependence," enabling the calculation of thermal changes along the cable route (Smolen and van der Spek 2003: 5). In this calculation, the fiber optic cable becomes "a very long continuous thermometer" (Tallon and O'Kane 2013: 2). The impurities of silica glass generate a kind of noise along the cable route, but they are not elements to be extracted. Rather, they are the means by which the earth itself can become a source of thermal signals.

These temperature variations, which can be used to register an array of activities (since all activities have a "thermal signature"), are proving critical to the excavation of geological matter. In "smart fields," they relay temperature changes inside oil wells and can be used to assess the effectiveness of valves. Slight shifts in temperature are used to determine the flow of different fluids, each of which has its own thermal behavior. In 2011, Roctest, a company specializing in geotechnical sensors, installed a line of fiber-optic cable at the world's largest copper mine in Chile's Atacama Desert. The cable, several kilometers long, was part of a monitoring system that would detect the infiltration of liquid acid through a dam. Temperature-sensing cables can detect leaks and are at times laid next to oil and gas pipelines for this reason. In mines, they are used to monitor for ventilation problems and potential explosions, and in underground natural gas storage facilities, they register available capacity. These practices of "distributed temperature sensing" use thermal shifts to index a vast array of environmental changes.

Thermal infrared imaging, more broadly discussed and visibly mediated than distributed temperature sensing, also transforms the earth into a set of signals and has been increasingly important to the mining industry. Lisa Parks (2014: 2518) notes that as thermal data is gathered by infrared imaging devices on planes and satellites, the earth is "codified as a set of absolute temperature values" and made available to new modes of surveillance and vertical administration. Like the technologies of distributed temperature sensing, these devices are made possible by the acute thermosensitivities of pure materials. Sensors composed of extraordinarily pure germanium, doped with impurities of mercury, can detect thermal infrared emissions in the range of 3–14 μm. In order to ensure that the minute changes registered by the germanium sensor are indeed from the targeted area rather than the sensor itself, its surrounding environment has to be cooled to between –243.15 degrees and –196.15 degrees Celsius, sometimes with liquid nitrogen or helium (Weng 1014: 7). The stabilization of the thermal environment described in the previous section thus, in turn, enables the remote detection of temperature.

The sensing of geophysical changes is possible not only because of the particular thermosensitivities of sensing instruments but also because all matter with a greater temperature than absolute zero, whether humans, minerals, or media technologies, emits thermal infrared energy. This enables the aerial mapping not only of forms of human and nonhuman life but also of mineral deposits. Each element and compound has a particular thermal signature: quartz and hydrous silica can be detected by the presence of their emission minima, around 8.40 and 8.95 μm (Rowan, Schmidt, and Mars 2006). As a result, thermal infrared detection has become standard as a first step in mineral and petroleum exploration. Thermal sensors have also been used to map existing mines, providing detailed data on soil types, vegetation, and other surface features.

The operations of thermal sensing appear to diverge from the techniques of purification or stabilization. Instead of managing materiality in ways that reduce the flux and flow of thermal forces, these technosocial arrangements seek out minute thermal differences, especially between minerals, as a way to locate and manage other geophysical phenomena. The environmental transformation of materials and their ever-present thermal emissions do not make them unruly matter but are instead productive variations to be mobilized as sources of capital. Yet these techniques, too, rely on the creation of increasingly pure materials and stabilized thermal environments. Without a controlled temperature baseline and the quantification of thermal emissions, variation cannot be registered and used as a means of environmental knowledge.

Thermocultures

The regulation of temperature sets conditions for how matter, whether the matter of human bodies, media technologies, or mineral ores, takes shape and circulates through the world. Perhaps most significantly for this article, thermal control is critical to establishing material and symbolic divisions. Apparatuses of thermal manipulation establish "cuts" that produce phenomena as usable and knowable elements of mediation, whether in the separation of an individual element or compound from others, in the maintenance of media's objectness, or in the distinction between minerals sensed by thermal imaging. Although this discussion has focused on the operations of seemingly tangible "hard" technologies such as the furnace and the air conditioner, the process of temperature manipulation is not merely a technical activity; it is a cultural practice that enfolds assumptions about what kinds of material transformation can and should take place. The organization of pure materials is crafted to generate particular forms and uses of digital media, prioritizing speed, consistency, and the binary encoding of culture. And it requires the relegation of other materials—deemed pollutants and impurities—to marginal spaces, whether mining dumps or the bodies exposed to them. Such practices both precede and expand beyond specific technologies.

The study of thermocultures, the modes by which temperature is managed and organized in embodied and culturally specific ways, offers a branching path to the geology of media, one that follows its metallurgical routes. If we locate the differentiation of copper and silicon as media elements not in the moment of excavation but rather in intensifying modalities of thermal control, practices of heating, in addition to mining, are genealogies of geological media—ones that quickly open to considerations of bodily difference. While mining has long been the "oldest and most masculine of industries" (Mercier and Gier 2007: 995), numerous archeological studies have observed that women's work in thermal manipulation, and the purification and reshaping of elements, was a part of the discovery of minerals and the development of metalworking. In the early history of mining in Kenya, women engaged in pot-making discovered many of the area's minerals. Notably, this happened during their work with heat and fire—when the pots were burned at the final stage of production, a change in color revealed minerals present in the clay (Amutabi and Lutta-Mukhebi 2001). In northwest Argentina, communal hearths used by women for food preparation were also used to produce copper artifacts. "Pyrotechnical processing," Joan Gero and Christina Scattolin (2002: 168, 170) report, occurred in a female-gendered space, and copper working blended "'difference' within productive households." The use of temperature to catalyze changes in materiality and to establish or complicate differences not only structured the recomposition of metals but also restructured the differentiation of bodily matter.

The gendering of thermal work was present not only in ancient times and in alchemical practices but extended through the twentieth century in the construction of computational technologies. Hyungsub Choi (2007: 770) observes that in the history of early transistors, "making junction transistors by the alloying technique was comparable to baking cookies. Workers, usually women, attached indium dots on either side of the germanium wafer and installed them in the furnace. Just as in baking cookies, two variables were crucial: temperature and time." Recent work on the production of computer hardware by scholars such as Lisa Nakamura (2014) and Kyle Stine (2015) have documented the racialization and gendering of the labor of semiconductor manufacturing. Nakamura's article "Indigenous Circuits" recounts the exploitation of Navajo women's labor by Fairchild Semiconductor and the ways that racialized and gendered cultural practices were drawn on as both a material and symbolic resource. Along this line of inquiry, though outside the scope of this article, similar questions could be asked about the historical connections between gendered thermocultural practices and the manufacturing of media.

A focus merely on the work of excavation at the mine, a task often relegated to men, obscures the role of thermocultures and techniques of geological processing in other kinds of gendered spaces, whether in pottery creation, food preparation, or media production. Such gendered differences have not been fully accounted for in geological history or in technological histories of heating and cooling. Writing in 1997, John F. Flynn (1997: 325) argued that even though "cooking in general, and breadmaking in particular, may be regarded as central to the empirical foundations of technology and science, even the most general references to either is consistently and conspicuously absent from standard historical surveys of Western technology," despite the many ties between cooking, alchemy, chemistry, and metallurgy. And yet almost twenty years later, things have not changed significantly—the materiality of thermocultures remains marginal, if not absent, in histories of media technologies.

Thermal control is both an operation that underlies the differentiations and homogeneity of contemporary media, and a set of practices that extend beyond the development of furnaces or air conditioners. Looking to the thermocultural practices that generate geological distinctions before the ground is even dug and long after minerals are excavated affords not only a different set of genealogical possibilities for media history but also a different conceptual orientation for future geologies of media. Thermal manipulation is ultimately a process of controlling the conditions in which materials are reactive or stable and in which transformations can occur. Every action and reaction is bound by its thermal state. The geology of media, then, entails looking at the states, thermal and otherwise, that make possible the transformation of earth into media—the conditions in which "non-mediatic" or "premediatic" materialities can be transformed into elements of mediation (Parikka 2013: 70, 2015: 4).

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Notes

1. Some notable exceptions include Jonathan Sterne and Dylan Mulvin's (2014) special issue "Media, Hot and Cold" in the *International Journal of Communication*, Finn Brunton's (2015) "Heat Exchanges," and Brian Jacobson's (2015) discussion of heat in early film studios. See also Starosielski 2012, 2014.
2. The significance of chemicals here should also not be underestimated. As Jennifer Gabrys (2011: 27) argues, the "transformation of silicon into an essential material of the information revolution was in part enabled . . . by an equally momentous revolution in chemicals."

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